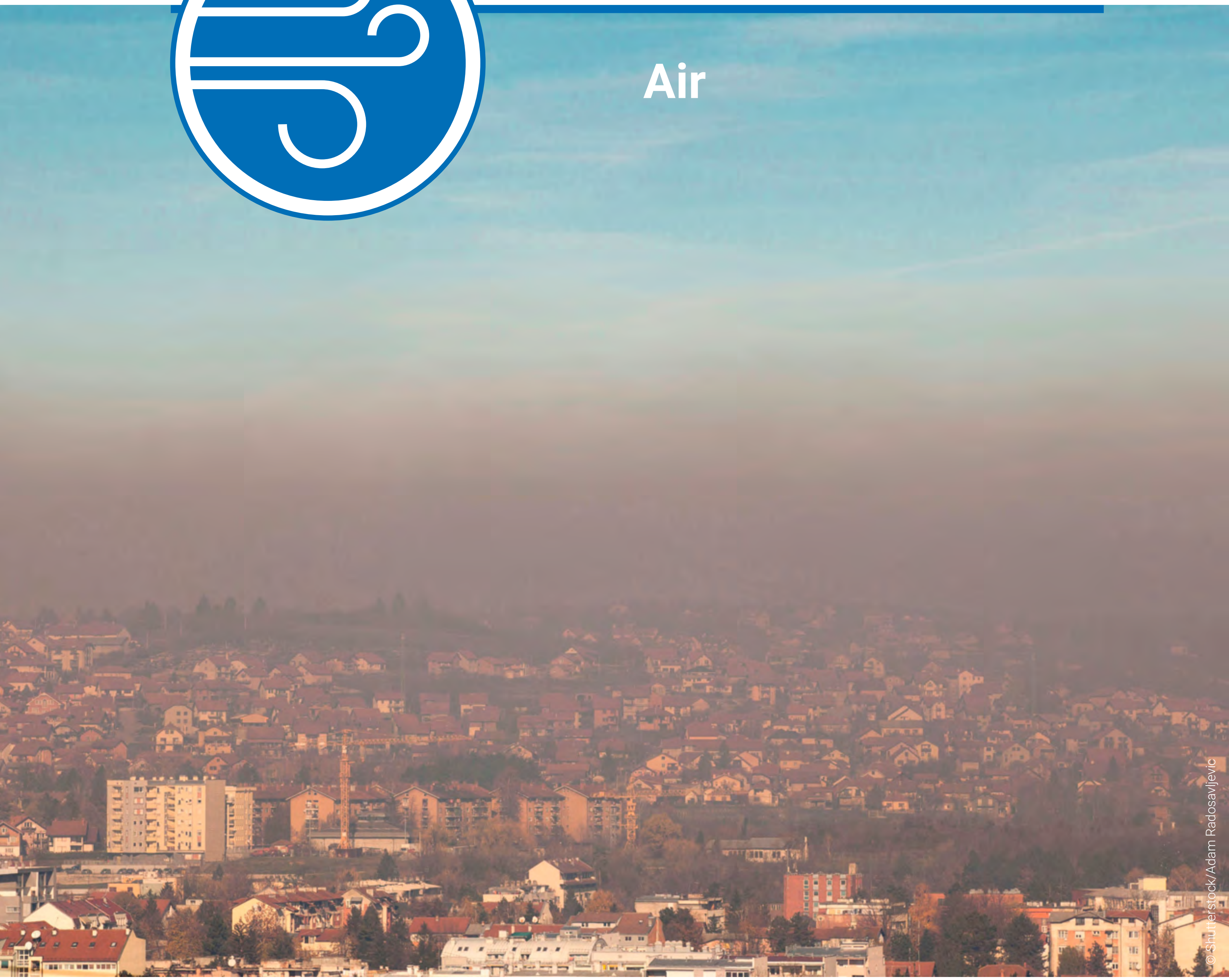
Chapter 5

Air



Coordinating Lead Authors: Phillip Dickerson (United States Environmental Protection Agency), Cristina Guerreiro (Norwegian Institute for Air Research), Terry Keating (United States Environmental Protection Agency), John Muthama Nzioka (University of Nairobi)

Lead Authors: Serena H. Chung (United States Environmental Protection Agency), Stefan Reis (Centre for Ecology and Hydrology)

Contributing Authors: Babatunde Joseph Abiodun (University of Cape Town), Kathryn Jennifer Bowen (Australian National University), Riyanti Djalante (United Nations University – Institute for the Advanced Study of Sustainability), James Grellier (European Centre for Environment and Human Health, University of Exeter), Fintan Hurley (Institute of Occupational Medicine), Andrei Kirilenko (University of Florida), Robyn Lucas (National Centre for Epidemiology and Population Health – The Australian National University), Caradee Y. Wright (Medical Research Council of South Africa)

GEO Fellow: HE Chenmin (Peking University)

Executive summary

Concentrations of CO_2 and other long-lived greenhouse gases (GHGs) continue to increase, driven mainly by people consuming fossil fuels to satisfy ever-increasing demands for energy (*well established*). {5.2.4}

Given the current concentrations of GHGs and their lifetime in the atmosphere, significant changes in climate and sea levels are unavoidable, with widespread consequences for people and the environment (*well established*). There is robust evidence that climate change and increased climate variability worsen existing poverty, exacerbate inequalities and trigger new vulnerabilities. However, even greater changes are expected in the future if action is not taken soon to halt GHG emissions. {5.3.4}

Climate change impacts include increased frequency and magnitude of heatwaves and storms (*established but incomplete*); changes in the distribution of disease vectors, exacerbation of air pollution episodes, and decreases in water supply and impacts on crop yields and food prices. {5.3.4}

Efforts to decrease emissions of short-lived climate pollutants (SLCP), specifically black carbon (BC), methane (CH_4), tropospheric ozone (O_3) and hydrofluorocarbons (HFCs), are a critical component of an integrated climate change mitigation and air quality management programme (*well established*). Along with rapid mitigation of long-lived GHG emissions, decreases in SLCP emissions achieve the objectives of the United Nations Framework Convention on Climate Change (UNFCCC). {5.2.4}

Air pollution is the most important environmental contributor to the global burden of disease, leading to an estimated 6 million to 7 million premature deaths annually and large economic losses (*established but incomplete*). Of those deaths, 2.6 million to 3.8 million deaths have been attributed to burning wood, coal, crop residue, dung and kerosene for cooking, heating and lighting. Another 3.2 million to 3.5 million deaths have been attributed to other sources of ambient air pollution. The monetary value of the global welfare losses has been estimated at US$5.1 trillion (or 6.6 per cent of global world product). {5.3.1}

People who are elderly, very young, sick and poor are more susceptible to air pollution, which can exacerbate pre-existing illnesses or conditions (*well established*). Exposures are highest for people living in urban areas in low- and middle-income countries and for the approximately 3 billion people who depend on burning solid fuels or kerosene to meet household energy needs. {5.3.1}

Globally, decreasing emission trends in some sectors and regions have been offset by increasing emission trends in rapidly developing and emerging economies and areas of rapid urbanization (*well established*). {5.2}

East and South Asia have the highest total number of deaths attributable to air pollution, due to large populations and cities with high levels of pollution (*well established*). These regions also bear the largest health burden caused by the production of goods consumed in other regions of the world, primarily Western Europe and North America. {5.3.1}

As controls have been placed on power plants, large industrial facilities and vehicles, the relative contributions of other sources have grown in importance *(well established).* Sources of pollution that are increasingly relevant to achieving air quality objectives include agriculture, domestic fuel burning, construction and other portable equipment, artisanal manufacturing and fires. The relative contributions of these sources to air quality problems differs from region to region, such that priorities for air pollution control may vary in different locations. {5.2.1}

Emissions of ozone-depleting substances (ODSs) have decreased dramatically as a result of the Montreal Protocol (*well established*). New studies provide robust evidence that stratospheric ozone over Antarctica has started to recover. Although stratospheric ozone concentrations in other regions have increased since 2000, the expected increase in total atmospheric column ozone and decrease in ultraviolet (UV) radiation reaching the Earth's surface have not been observed outside Antarctica due to natural variability, increases in GHGs, and changes in attenuation of the UV radiation by tropospheric ozone, clouds and aerosols. {5.2.3}

International agreements have been successful in addressing specific chemicals, but new chemical risks are emerging (*established but incomplete*). Environmental concentrations of persistent organic pollutants (POPs) have been reduced in Europe, North America, Asia and the Pacific, and the Arctic. {5.2.2}

Rapid development and urbanization combined with insufficient environmental governance in many regions suggest that climate change and air pollution are likely to worsen before they improve without additional policy interventions *(well established).* However, future policy efforts can build upon renewed attention to these issues in international forums and several decades of experience with various governance strategies in different countries. {5.4}

5.1 Introduction

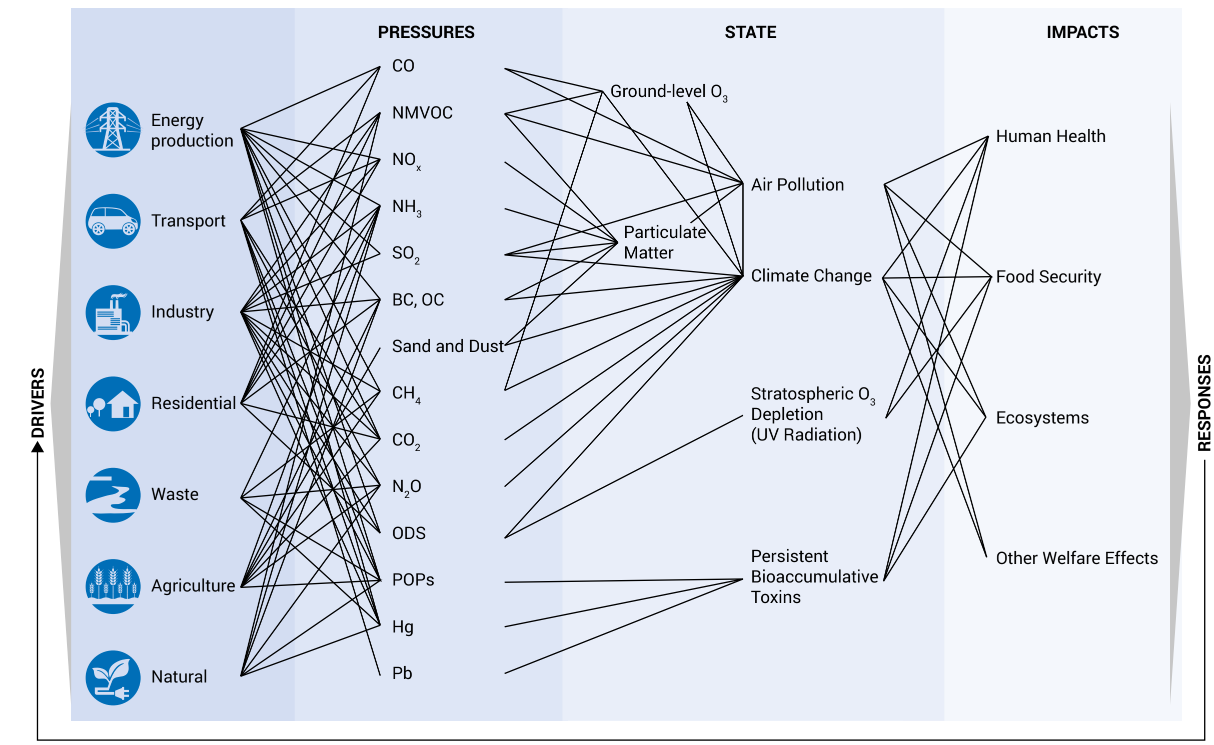
Emissions generated by human activity have changed the composition of the Earth's atmosphere, with consequences for the health of people and the planet. The impacts of human activity on the atmosphere are often framed in terms of four separate challenges: air pollution; climate change; stratospheric ozone depletion; and persistent, bioaccumulative, toxic substances (PBT) (Abelkop, Graham and Royer 2017). The causes of these four challenges, their effects on atmospheric composition and meteorological processes, and their impacts on humans and ecosystems are closely intertwined **(see Figure 5.1)**. Solutions to these challenges are also interrelated, as changes in lifestyle, technology and policy alter emissions of multiple pollutants simultaneously with a variety of interrelated implications. This chapter describes these four challenges together following the Drivers, Pressures, State, Impact, Response (DPSIR) framework (see Section 1.6).

Since the fifth Global Environment Outlook (GEO-5) was published in 2012, a number of developments have focused international attention on changing atmospheric composition. Estimates of the global burden of disease contributed by air pollution have doubled (comparing assessments published in 2004, 2012 and 2017) primarily due to new exposure estimates informed by satellite-borne instruments (Lim *et al.* 2012; Cohen *et al.* 2017). The United Nations Environment Assembly of the United Nations Environment Programme (UNEA) (2014; 2017) and World Health Assembly of the World Health Organization (WHO) (2015) have responded with resolutions to encourage national-level actions to address air pollution. Concentrations of major GHGs are still growing strongly (World Meteorological Organization [WMO] 2017a) and indicators of climate change

Table 5.1: Some atmospheric chemical components

BC	black carbon
CFCs	chlorofluorocarbons
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
GHGs	greenhouse gases
HCFCs	hydrochlorofluorocarbons
HFCs	hydrofluorocarbons
Hg	mercury
N_2O	nitrous oxide
NH_3	ammonia
NMVOC	non-methane volatile organic compounds
NO	nitrogen oxide
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
O_3	ozone, tropospheric and stratospheric
OC	organic carbon
ODS	ozone-depleting substances
PAHs	polycyclic aromatic hydrocarbons
Pb	lead
PBDE	polybrominated diphenyl ethers
PBTs	persistent, bioaccumulative, toxic chemicals (includes POPs, metals)
PCB	polychlorinated biphenyl
PFAS	per- and polyfluoroalkyl substances
PM	particulate matter
PM_{10}	PM less than 10 µm in diameter
$PM_{2.5}$	PM less than 2.5 µm in diameter
POPs	persistent organic pollutants (as defined by international agreements)
SO_2	sulphur dioxide

Figure 5.1: Primary linkages between pressures, state and impacts of atmospheric change



This figure is intended as a road map for the reader, showing the relationships between the main topics and pollutants discussed in this chapter. Chemical symbols and abbreviations are defined in Table 5.1.

have continued to accumulate. Targets in the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) expired but were replaced by new ones under the Doha Amendment and new commitments under the Paris Agreement (UNFCCC 2016). Complementing the work of the UNFCCC, new efforts have targeted reductions of short-lived climate pollutants (SLCPs) from specific sectors with benefits for climate change mitigation and human health (Climate and Clean Air Coalition [CCAC] 2015). As stratospheric ozone (O_3) has continued its recovery, the Kigali Amendment to the Montreal Protocol (United Nations 2016a) has harnessed this successful international agreement to help mitigate the climate impacts of hydrofluorocarbons (HFCs), originally introduced as substitutes for ozone-depleting substances (ODS). Emissions of mercury (Hg) have declined in some regions and increased in others. Emissions of some banned persistent organic pollutants (POPs) have declined due to the implementation of international agreements. However, atmospheric burdens of other POPs and PBTs remain at levels of concern, and new chemical risks have been identified (United Nations Environment Programme [UNEP] 2017a).

Efforts to achieve each of the Sustainable Development Goals (SDGs) are linked directly or indirectly to mitigating air emissions and changes to atmospheric composition, as shown in **Figure 5.2**.

In the GEO-6 regional assessments, air pollution, climate change and energy development, as well as the intersection of these three issues, were identified as top priorities in every region. Growing cities, energy, and transportation demand were consistently identified as issues of concern. Indoor air pollution and access to clean household energy were priorities in Africa and Asia. Other regional priorities highlight differences in the institutional capacities of governments in different regions: improving observational networks (Africa, Latin America and the Caribbean, West Asia), strengthening governance (Asia, Latin America and the Caribbean), and understanding costs and benefits of mitigation measures (Asia). The following sections build upon the GEO-6 regional assessments to explore the state of these challenges from a global perspective.

5.2 Pressures: emissions

People alter the atmosphere primarily by generating emissions. Trends in human-caused emissions are driven by changes in population, urbanization, economic activity, technology and climate ('the drivers'), as well as by behavioural choices, including lifestyle, and conflict. In turn, these drivers are influenced by policies ('responses'). Natural emission sources, including emissions from vegetation, soils, wildfires, and windblown sand and dust, also contribute to emissions, but can be affected by people (e.g. through land-use change).

Although an increasing amount of emissions information in some GEO regions is publicly available, there is no global reporting programme applicable to all sources and pollutants and no comprehensive emissions data repository. The Aarhus Convention and its Protocol on Pollutant Release and Transfer Registers (PRTR) aspires to establish a global network, building on the work of the United Nations Economic Commission for Europe (UNECE) and the Organisation for Economic Co-operation and Development (OECD) (see http://prtr.net). Currently, compiling a consistent global emissions inventory requires research effort. This assessment uses the latest anthropogenic emissions data developed using the Community Emissions Data System (CEDS), an open source, global emissions inventory data system that was developed

Figure 5.2: Linkages between changes in atmospheric composition and achievement of the Sustainable Development Goals

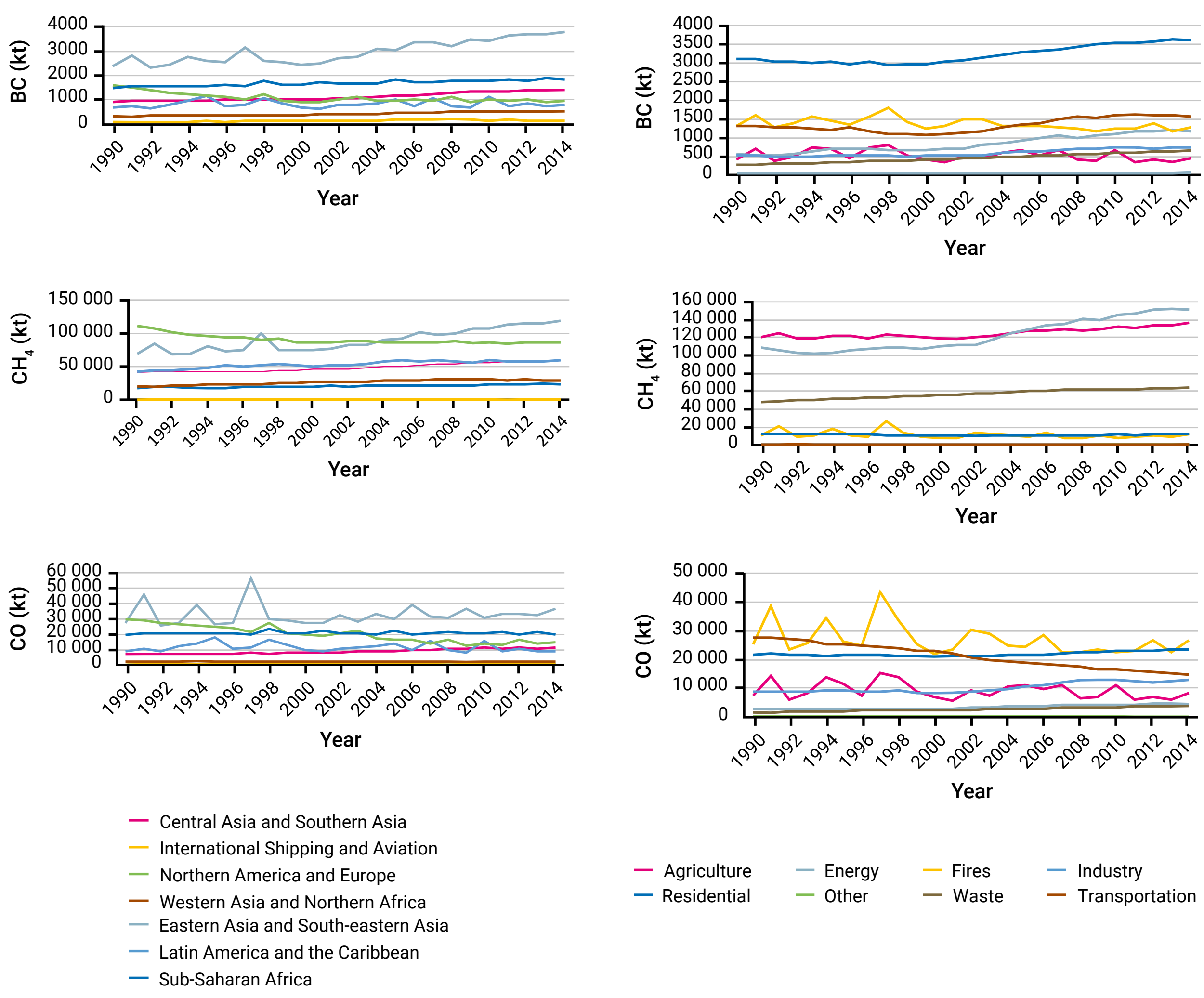
Direct linkages are shown with bold arrows, indirect linkages with light arrows.

to provide consistent long-term emission trends for use in global atmospheric modelling efforts, such as those supporting the preparation of Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Report (Hoesly *et al.* 2018). Open biomass burning emissions, whether anthropogenic or natural, are drawn from a separate inventory created for global modelling efforts by merging information from satellite-based estimates, sedimentary charcoal records, historical visibility records and multiple fire models (van Marle *et al.* 2017). Together, these data sets provide an up-to-date and consistent basis to examine trends for most air pollutants and greenhouse gases (GHGs) **(see Figure 5.3)**.

Globally, anthropogenic carbon dioxide (CO_2) emissions increased by more than 40 per cent over the period 1990-2014, driven by large increases in Asia and counteracted by small declines in North America and Europe. Sulphur dioxide (SO_2) emissions are the only ones to have declined globally during this period, with increases of more than 50 per cent in Asia offset by a more than 75 per cent decrease in North America and Europe. In recent years, emissions of SO_2 and nitrogen oxides (NO_X) have begun to decline in East Asia. The inclusion of wild and agricultural fires significantly increases the inter-annual variability of emissions of non-methane volatile organic compounds (NMVOC), carbon monoxide (CO), black carbon (BC) and organic carbon (OC).

The emissions data presented here are best estimates with different degrees of uncertainty depending on pollutant, sector, region and time period. Hoesly *et al.* (2018) found that CEDS estimates are slightly higher than previous global inventories (e.g. Lamarque *et al.* 2010; European Commission 2016). In general, estimates of CO_2 and SO_2 emissions have uncertainties on the order of ±10 per cent for a 5-95 per cent confidence interval, whereas BC and OC emissions have uncertainties on the order of a factor of two. Uncertainties for CO, NO_X, NMVOC and ammonia (NH_3) emissions lie in between these two endpoints (Hoesly *et al.* 2018). Uncertainty also varies by sector: emissions from large electricity generation plants are well characterized, whereas emissions generated by military conflicts are not well understood or commonly included in inventories.

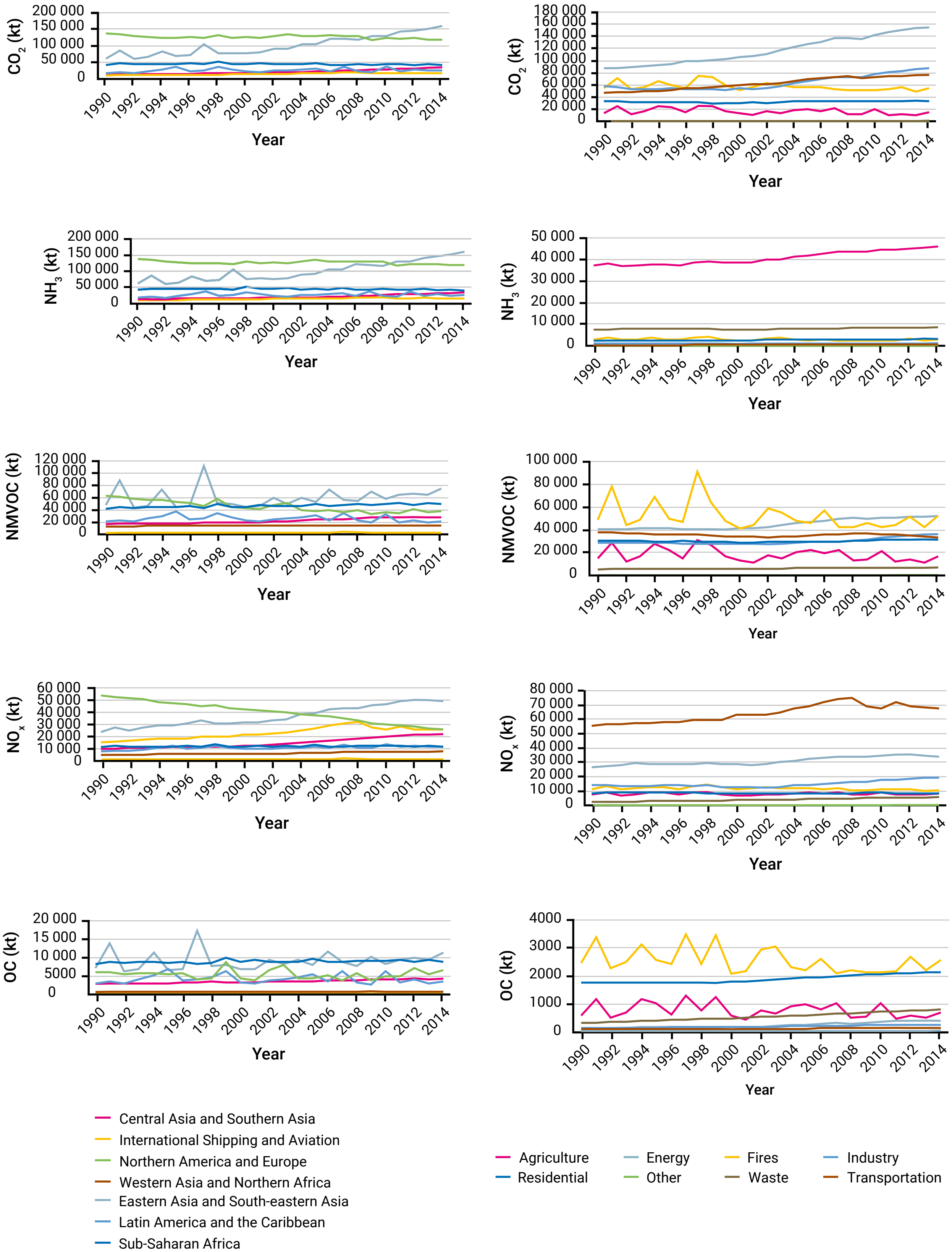
Figure 5.3: Annual emission trends from 1990 to 2014 in kilotons by pollutant, region and sector



Source: Hoesly *et al.* (2018).

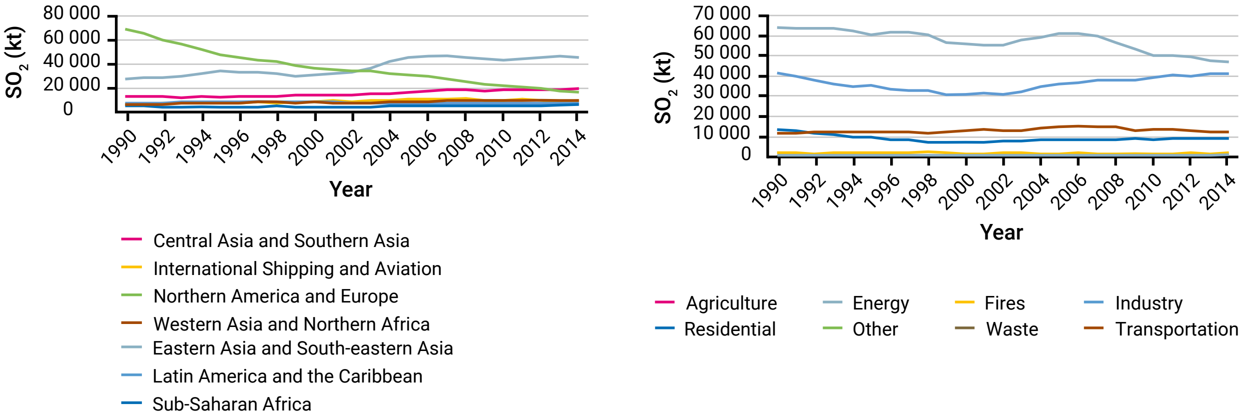
5

Figure 5.3 (continued): Annual emission trends from 1990 to 2014 in kilotons by pollutant, region and sector



Source: Hoesly *et al.* (2018).

Figure 5.3 (continued): Annual emission trends from 1990 to 2014 in kilotons by pollutant, region and sector



Source: Hoesly *et al.* (2018).

There are considerable gaps in available emissions data for POPs, which include pesticides, industrial chemicals and products of incomplete combustion or chemical reactions. Available data in Europe, America and Central Asia indicate that emissions decreased significantly between 1990 and 2012 for the most studied POPs, due to regulations, including the Stockholm Convention (UNEP 2014a; UNEP 2014b; UNEP 2015a; UNEP 2015b). Nevertheless, alongside the growing number of listed POPs and candidate substances, unregulated POPs emissions may be increasing. Many commercial products contain unknown quantities and types of unregulated POPs, often with unknown effects (see also Section 4.3.3).

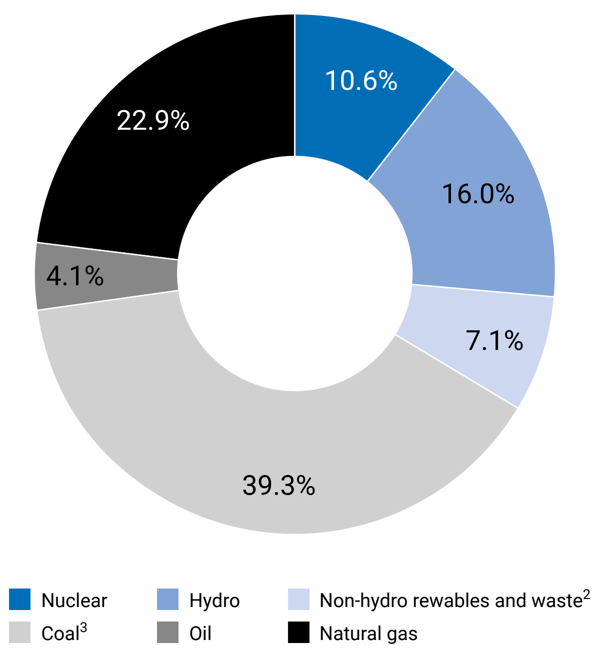
The UNEP Global Mercury Assessment estimated that anthropogenic Hg emissions to air were 2,220 (2,000-2,820) (metric) tons/year for 2015 (UNEP 2013a). Globally, artisanal and small-scale gold mining (ASGM) was responsible for about 38 per cent of total anthropogenic Hg emissions to air in 2015, followed by coal combustion (about 21 per cent), non-ferrous metal production (about 15 per cent) and cement production (about 11 per cent). Asia is the main source region, contributing about 49 per cent of 2015 global anthropogenic Hg emissions, followed by South America (18 per cent) and sub-Saharan Africa (16 per cent). Current anthropogenic sources contribute about 30 per cent of annual Hg emissions to air, while natural geological sources contribute about 10 per cent. The remaining 60 per cent comes from 're-emissions' of previously released Hg from soils and oceans, mostly from anthropogenic sources (UNEP 2013a).

Globally, both the production and consumption of ODS, and thus ODS emissions, declined by more than 99 per cent between 1990 and 2016 (UNEP 2017b). Chlorofluorocarbons (CFCs) and halons, the most potent ozone depleters, have been replaced by shorter-lived hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs), although recent measurements suggest that new emissions of trichlorofluoromethane (CFC-11) may be occurring (Montzka *et al.* 2018). The less-depleting HCFCs are now being phased out in favour of chemicals that do not contribute to ozone depletion. Concerns about the potential future contribution of HFCs to climate change led to the 2016 Kigali Amendment to the Montreal Protocol, which will limit future HFC emissions.

5.2.1 Electricity and fuel production

The electricity and fuel production sector (labelled 'energy' in **Figure 5.3**) is the largest anthropogenic emitting sector of CO_2, methane (CH_4), SO_2 and NMVOC, and the main emitting sector of other air pollutants. Within the sector, electricity generation contributed around 70 per cent of CO_2, 71 per cent of SO_2 and 72 per cent of NO_X in 2014 (Hoesly *et al.* 2018).

Figure 5.4: Global fuel shares of electricity generation in 2015[1]



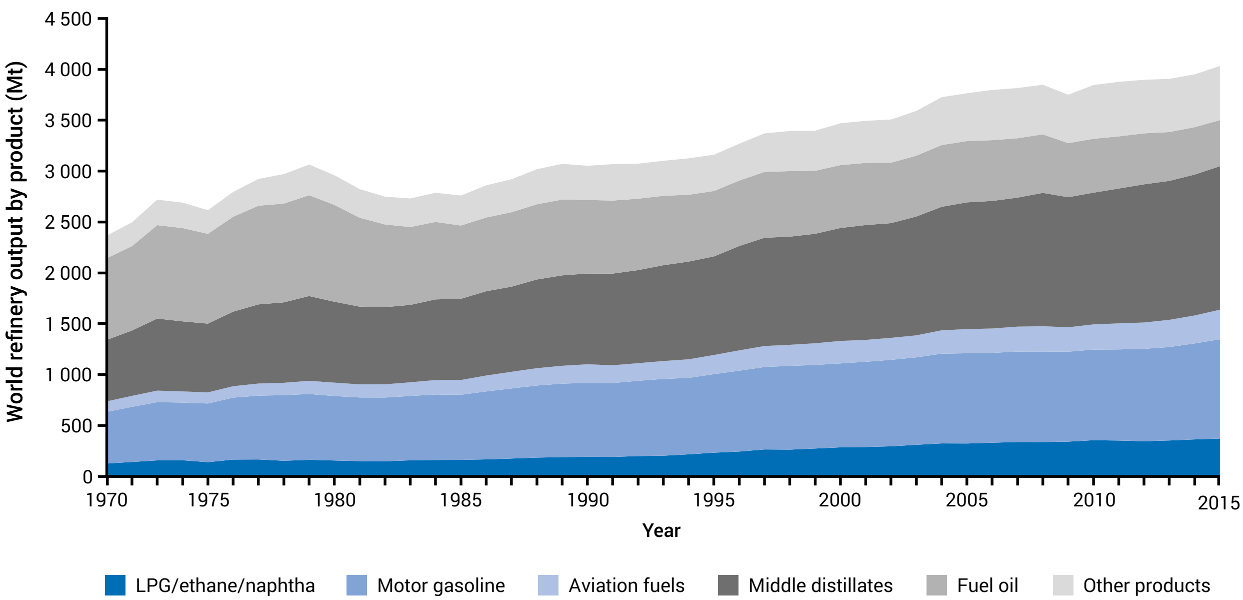
Notes: [1] Excludes electricity generation from pumped storage. [2] Includes geothermal, solar, wind, heat, etc. [3] Peat and oil shale are aggregated with coal.

Source: IEA (2017).

Despite increases in renewable energy capacity, fossil fuels still dominate the global power system (see **Figure 5.5**). Three-quarters of the sector's SO_2 emissions, 70 per cent of its NO_X emissions and over 90 per cent of those of primary particulate matter less than 2.5 μm in diameter ($PM_{2.5}$) are from coal-fired plants. Coal combustion is also the second most important anthropogenic source of global Hg emissions (International Energy Agency [IEA] 2016a). In 2015, gas-fired generation emitted close to 20 per cent of NO_X from power generation, but barely any SO_2 or primary $PM_{2.5}$ (IEA 2016a).

From 1990 to 2015, global petroleum fuel production saw slow but sustained growth (see **Figure 5.5**). CH_4 and NMVOC emissions from fuel production showed a corresponding increase (**Figure 5.3**). However, for electricity generation, production doubled between 1990 and 2015 (**Figure 5.6**),

Figure 5.5: World petroleum refinery output by-product (million tons)



Source: IEA (2017).

Figure 5.6: World electricity generation by fuel (terawatt hours)[1]